AS Unit 1: Basic Biochemistry and Cell Organisation

Name:	Date:

Topic 1.5 Nucleic Acids and their functions – Page 1

From the syllabus:

(a) the structure of nucleotides (pentose sugar, phosphate, organic base)

(b) the importance of chemical energy in biological processes

(c) the central role of ATP as an energy carrier and its use in the liberation of energy for cellular activity

(d) the structure of ATP

(e) the structure of nucleic acids: DNA bases: purines-adenine and guanine, pyrimidines-cytosine and thymine; complementary base pair rule; hydrogen bonding and the double helix; antiparallel strands

(f) the similarities and differences in the structure of RNA and DNA

(g) the two major functions of DNA; replication and protein synthesis

(h) the semi-conservative replication of DNA including the roles of DNA polymerase and helicase and be able to use evidence from the Meselson and Stahl experiments

(i) the term genetic code

(j) the triplet code for amino acids

(k) exons as regions of DNA that contain the code for proteins and that between the exons are regions of non-coding DNA called introns

(l) the transcription of DNA to produce messenger RNA

(m) the translation of mRNA using ribosomes and the structure and function of transfer RNA, to synthesise proteins

(n) the 'one gene - one polypeptide' hypothesis

(o) the further modification and combination of some polypeptides

SPECIFIED PRACTICAL WORK

- Simple extraction of DNA from living material

I. Nucleic Acids and their Functions - **ATP**

		Completed
1.	Go through the PowerPoint	
2.	Read the notes p - and complete any questions	
3.	Compete the worksheets on page • WJEC Textbook (new one not released yet but read the correct section) • Toole and Toole	
4.	Complete the worksheets p 8-9	
5.	Extension: Read the BIOFACTSHEET on ATP and have a go at the questions at the end.	

Start of topic checklist for NUCLEIC ACIDS AND THEIR FUNCTIONS

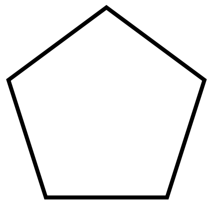
Tick as appropriate:
RED : I do not know about this
AMBER: I have heard about this but have not learned this yet. I am unsure on this.
GREEN: I have heard about this and I have learned this. I am confident about this.

Topic	RED	AMBER	GREEN
1. The components of a nucleotide are pentose sugar, phosphate plus organic base, which contains nitrogen.			
2. Chemical Energy is contained within food substances.			
3. Energy may be converted from one form to another.			
4. Green plants are able to convert light energy into chemical energy. All living organisms are able to convert chemical energy to other energy forms.			
5. Be able to label ATP (adenosine triphosphate): ribose sugar, nitrogenous base and three phosphate groups joined together.			
6. Energy is required to join ADP and phosphate to form ATP and this is an endergonic reaction.			
7. Energy is released when ATP is broken down into ADP and phosphate and this is an exergonic reaction; this is linked to energy- requiring reactions e.g. active transport, muscle contraction, synthesis of organic chemicals.			
8. Appreciate that ATP acts as an energy carrier in cells and all organisms use it so it is known as a 'universal energy currency in living organisms'.			
9. Nucleotide bases are purines or pyrimidines, linked by condensation reactions to form polymers, RNA and DNA, which can be represented in symbolic form.			
10. DNA consists of two chains linked via the base pairs, by hydrogen bonds, to form a double helix.			
11. The base pairs are C-G and A –T but in RNA thymine is replaced by uracil.			
12. DNA has two major functions: replication, in dividing cells, and carrying the information for protein synthesis in all cells, including those in future generations.			
13. Replication allows accurate copying of DNA for cell division.			
14. Know the main features of semi-conservative replication including the role of DNA polymerase and be able to draw a representative diagram.			
15. Be able to interpret evidence from the Meselson-Stahl experiment.			
16. DNA is the starting point for protein synthesis since the sequence of bases on DNA (genetic code) determines the primary structure of a protein.			
17. Each amino acid in a polypeptide is coded for by three bases, the triplet code, called the codon.			
18. The portion of DNA, which codes for a whole polypeptide, is called a gene. This is the basis of the 'one gene one polypeptide' hypothesis.			
19. Transcription is the mechanism by which the base sequence of a gene on a DNA strand is converted into			

the complimentary base sequence on mRNA.			
20. RNA polymerase links to DNA at the beginning of the sequence to be transcribed and part of the double helix unwinds. Only one of the DNA strands is used as a template.			
21. As RNA polymerase moves along the strand it picks up appropriate free RNA nucleotides from the nucleoplasm (having entered the nucleus from the cytoplasm) and joins guanine to exposed cytosine, but joins uracil to the DNA's adenine forming single stranded mRNA.			
22. At the end of the sequence mRNA detaches and the DNA rewinds.			
23. Exons are regions within the DNA gene that codes for protein and inbetween the exons are regions of non-coding DNA called introns. These introns are removed from the mRNA transcript before translation in a process called post-transcriptional modification.			
24. mRNA transfers nucleotides through nuclear pores to the cytoplasm where it attaches to ribosomes consisting of ribosomal RNA and protein.			
25. mRNA is held by a ribosome which has two transfer RNA (tRNA) binding sites. One site binds tRNA carrying the amino acid, which has been joined to the growing polypeptide chain while the other site is for tRNA carrying the next amino acid in the sequence.			
26. An amino acid is activated by ATP and is attached to a specific tRNA molecule, which carries an amino acid at one end and an anticodon at the other.			
27. Translation by ribosomes allows the assembly of amino acids into polypeptides according to the original DNA code. A ribosomal enzyme catalyses peptide bond formation between an amino acid on one tRNA and the growing polypeptide on the other tRNA.			
28. A ribosome passes along mRNA, one codon at a time, tRNA with the appropriate anticodon fills the vacant slot and the amino acid forms a peptide bond with the last member of the chain using energy from ATP, until a stop codon is reached.			
29. The polypeptides may be further modified and a protein may consist of more than one polypeptide.			
30. These modifications will involve the Golgi body.			
31. Be able to interpret data, using tables listing amino acids and their corresponding mRNA codons.			

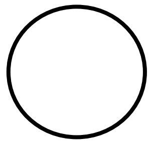
Nucleotides have 3 basic components a pentose sugar, a phosphate group and an organic nitrogen-containing base.
The nucleotide of DNA consists of three parts:

- Deoxyribose (a pentose sugar)



What does 'a pentose sugar' mean?

- Phosphate group (H_3PO_4)



What three elements does a phosphate group contain?

- An organic nitrogen-containing base.

If the base is described as 'organic' and nitrogen containing, what 2 elements must it contain?

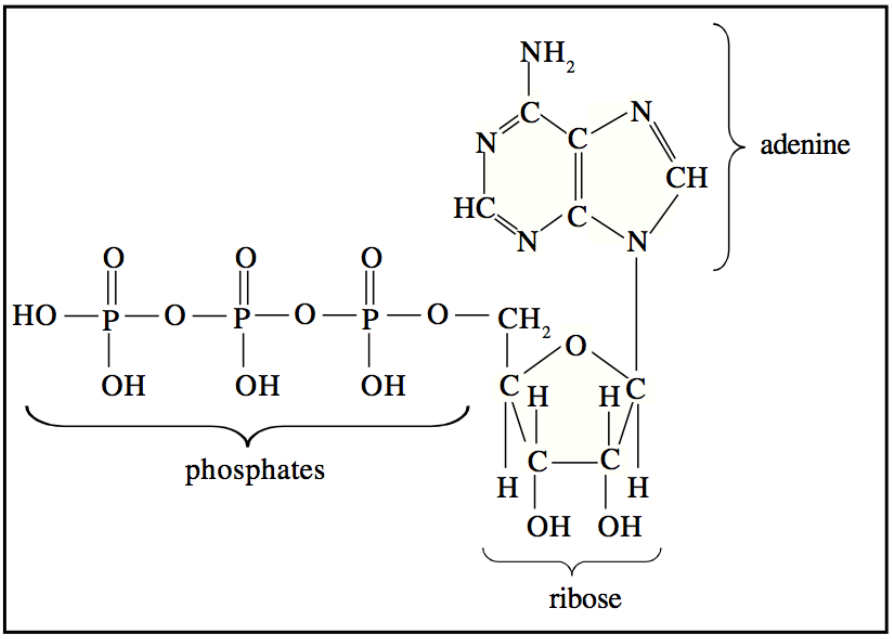
Nucleotides can either be polymerized together to form nucleic acids (this will be covered later) or on their own they have important roles as suppliers of energy (ATP) and their derivatives form another important group of coenzymes that are involved in the transport of protons and electrons within the cell (NAD and FAD).

Energy
Energy is neither created or destroyed it just gets converted from one form to another.

The flow of energy through a system occurs in three stages:
1. Plants produce organic molecules
2. Molecules are used in respiration to make ATP
3. ATP is used to do work in the cell

All cells require energy to do work; they use ATP as a source of energy.

The Structure of ATP

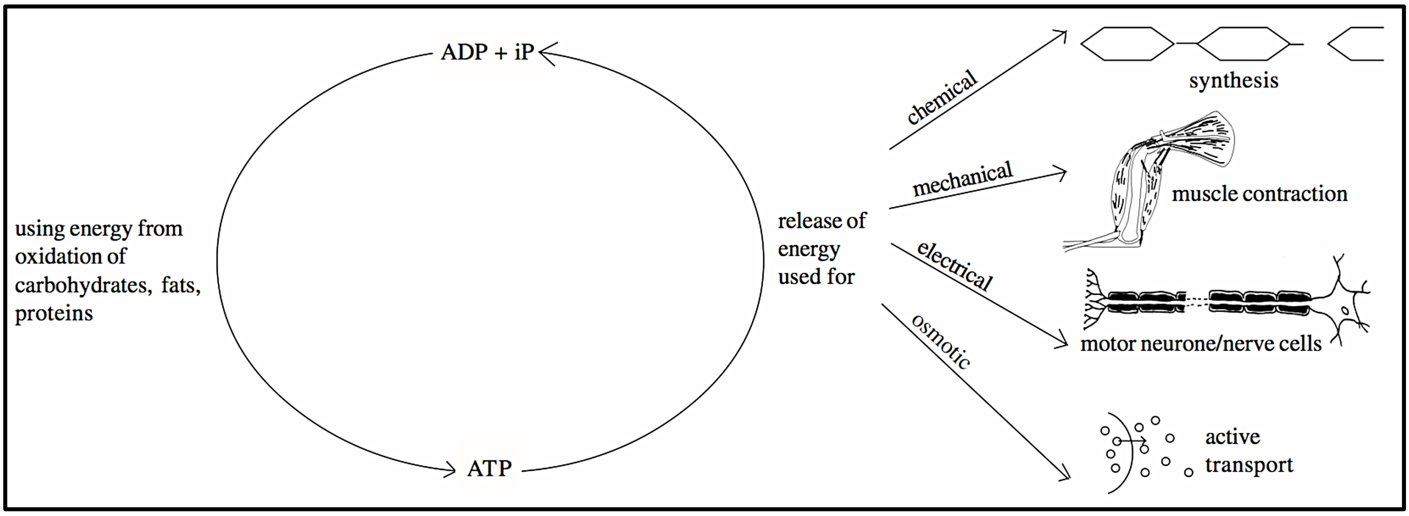


ATP is a nucleotide made up of a ribose (a pentose sugar), three phosphate groups and adenine (an organic nitrogenous base). Adenine and ribose are known collectively as adenosine so when attached to three phosphate groups it is referred to as adenosine **tri**phosphate.

What do you think it is called when only 2 phosphate groups are attached?

ATP is made by adding a phosphate group (Pi) to an ADP molecule; this process is an endergonic reaction. The energy to carry out this reaction primarily comes from energy released during (the oxidation of carbohydrates and fats) respiration.

When ATP is used to do work in the cell the phosphate group is removed ATP – Pi to form ADP, this is an exergonic reaction and the energy it releases can be used to carry out work in the cell. (When work needs to be done it is coupled to the hydrolysis of ATP).



ATP is often referred to as the **universal energy currency**.

Why do you think it is called universal?

It is referred to as a currency because it enables a cell to do work for example the synthesis of new molecules such as proteins and DNA; the transport of substances into and out of the cells by process such as active transport and muscle contraction.

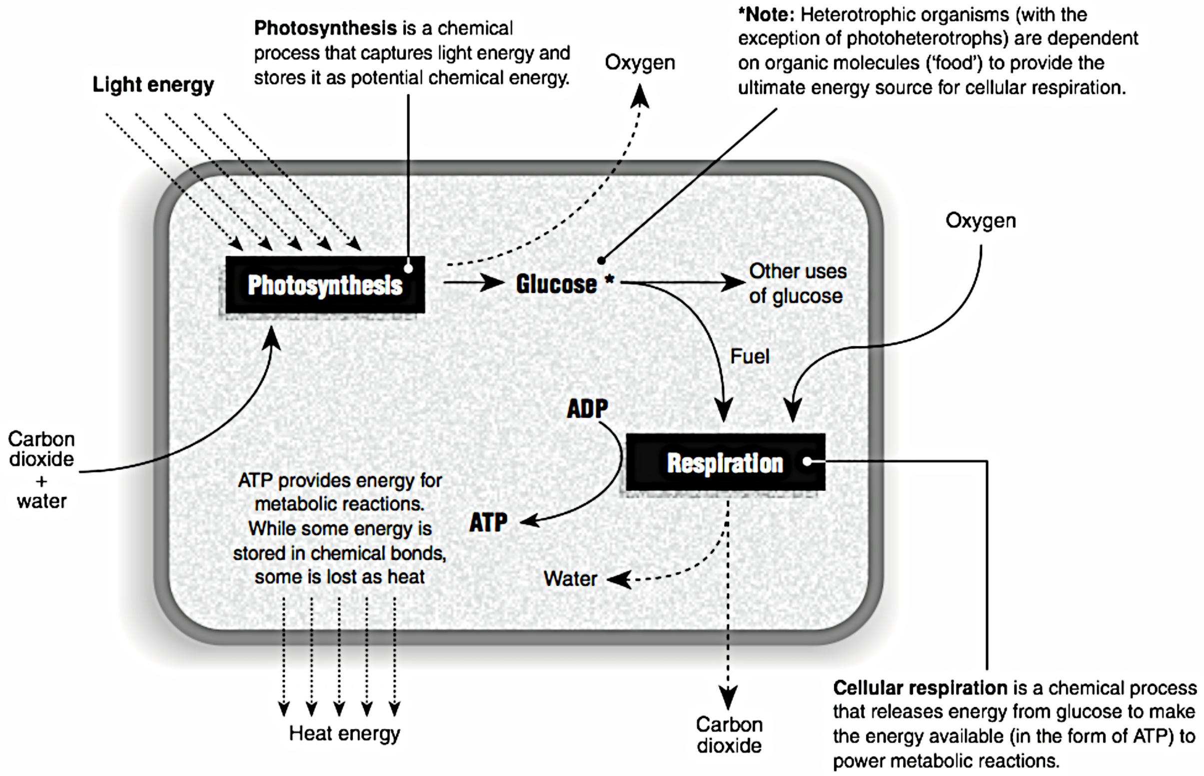
It is great at its job because energy can be released quickly, only one bond needs to be broken and one enzyme used and it will produce 30.6KJ/mole.

It is also sometimes referred to as a universal energy carrier. In this context the word refers to the fact that it is soluble and can easily be transported across membranes.

Energy in Cells

A summary of the flow of energy within a plant cell is illustrated below. Animal cells have a similar flow except the glucose is supplied by ingestion rather than by photosynthesis. The energy not immediately stored in chemical bonds is lost as heat. Note the role of ATP; it is made in cellular respiration and provides the energy for metabolic reactions, including photosynthesis.

Energy Transformations in a Photosynthetic Plant Cell



1. Distinguish between **heterotrophs**, **photosynthetic autotrophs**, and **chemosynthetic autotrophs** with respect to how these organisms derive their source of energy for metabolism:

____

____

____

____

____

____

2. In 1977, scientists working near the Galapagos Islands in the equatorial eastern Pacific found warm water spewing from cracks in the mid-oceanic ridges 2600 metres below the surface. Clustered around these hydrothermal vents were strange and beautiful creatures new to science. The entire community depends on sulfur-oxidising bacteria that use hydrogen sulfide dissolved in the venting water as an energy source to manufacture carbohydrates. This process is similar to photosynthesis, but does not rely on sunlight to provide the energy for generating ATP and fixing carbon:

   (a) Explain why a community based on photosynthetic organisms is not found at this site: ______________________

   ____

   (b) Name the ultimate energy source for the bacteria: ______________________

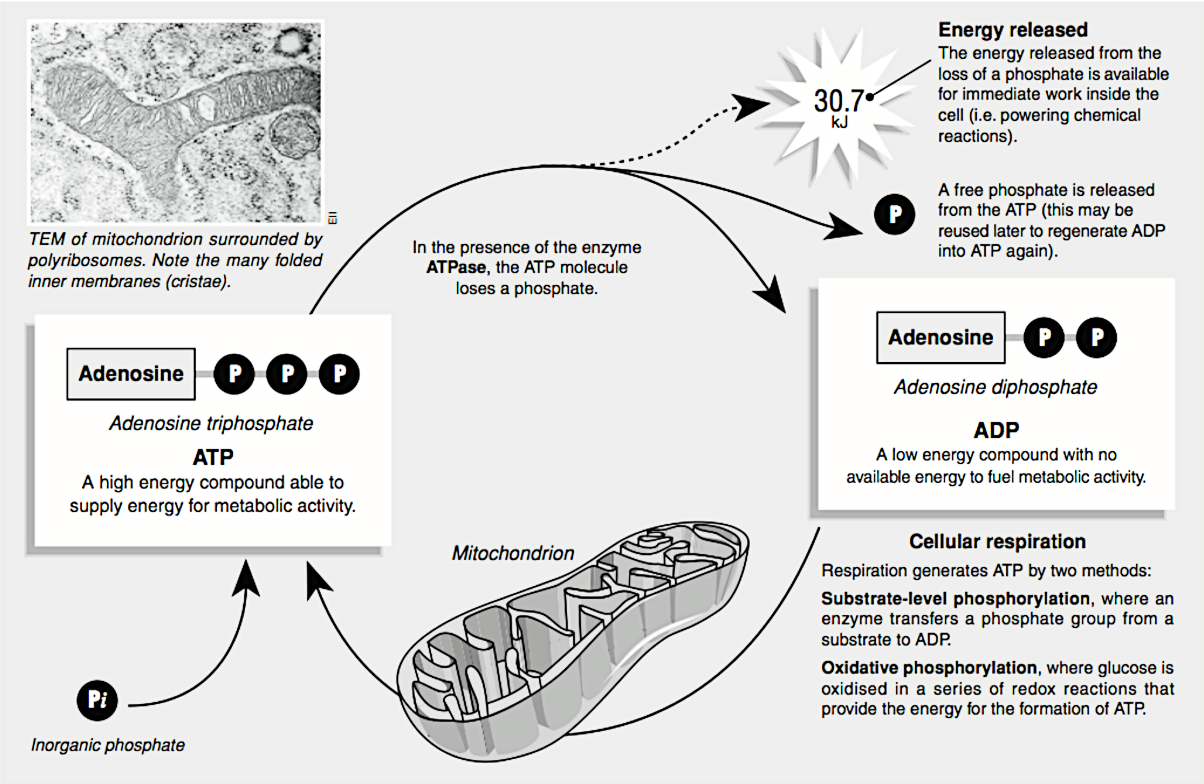
   (c) This same chemical that provides the bacteria with energy is also toxic to the process of cellular respiration; a problem that the animals living in the habitat have resolved by evolving various adaptations. Explain what would happen if these animals did not possess adaptations to reduce the toxic effect on cellular respiration:

   ____

   (d) Name the energy source classification for these sulfur-oxidising bacteria: ______________________

The Role of ATP in Cells

The molecule ATP (adenosine triphosphate) is the universal energy carrier for the cell. ATP can release its energy quickly; only one chemical reaction (hydrolysis of the terminal phosphate) is required. This reaction is catalysed by the enzyme ATPase. Once ATP has released its energy, it becomes ADP (adenosine diphosphate), a low energy molecule that can be recharged by adding a phosphate. This requires energy, which is supplied by the controlled breakdown of respiratory substrates in cellular respiration. The most common respiratory substrate is glucose, but other molecules (e.g. fats or proteins) may also be used.



1. Describe how ATP acts as a supplier of energy to power metabolic reactions: ____________________

____

2. Name the immediate source of energy used to reform ATP from ADP molecules: ____________________
3. Name the process of re-energizing ADP into ATP molecules: ____________________
4. Name the ultimate source of energy for plants: ____________________
5. Name the ultimate source of energy for animals: ____________________
6. Explain in what way the ADP/ATP system can be likened to a rechargeable battery: ____________________

____

7. In the following table, use brief statements to contrast photosynthesis and respiration in terms of the following:

Feature	Photosynthesis	Cellular respiration
Starting materials		
Waste products		
Role of hydrogen carriers: NAD, NADP		
Role of ATP		
Overall biological role		

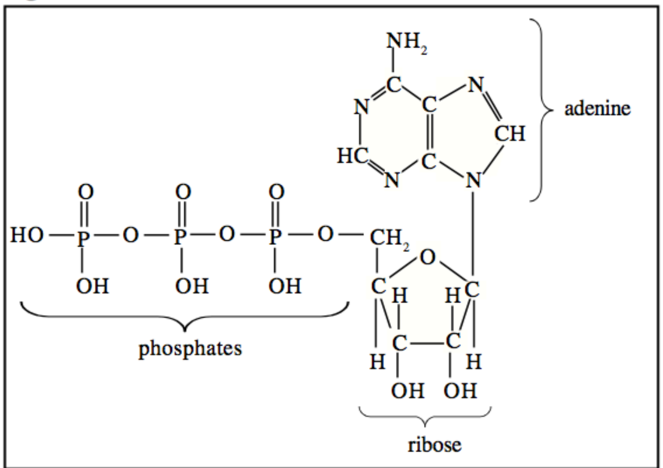
Bio Factsheet

www.curriculumpress.co.uk Number 129

ATP -What it is, What it does

ATP is a nucleotide composed of adenine (a nitrogenous base), ribose (the 5-carbon or pentose sugar found in RNA) and three phosphate groups (Fig 1).

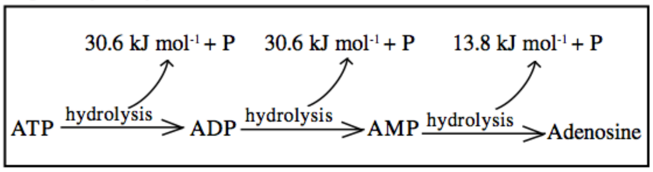
Fig 1. Structure of ATP



The combination of adenine with ribose makes adenosine. If one phosphate group is attached we have adenosine monophosphate (AMP). If a second phosphate becomes attached we have adenosine diphosphate (ADP) and a third phosphate gives us ATP.

ATP is sometimes referred to as energy currency. This is because all living organisms – from bacteria to nettles to crocodiles – use ATP for energy conversion. ATP is small and water soluble, properties which make it easy to transport. When ATP is hydrolysed into ADP i.e when one of the phosphate groups is removed in a reaction involving water, 30.6 kJ mol^{-1} energy is released. Similarly, the hydrolysis of ADP into AMP releases 30.6 kJ mol^{-1} of energy. Finally, the hydrolysis of AMP into adenosine yields 13.8 kJ mol^{-1} (Fig 2).

Fig 2. Hydrolysis of ATP



This energy can be used by the cell for hundreds of different chemical reactions or for muscle contraction or active transport etc. (Fig 3)

Equally importantly, when energy is released by, for example, the breakdown of carbohydrate during respiration, the released energy is captured by ADP that is thus converted into ATP. The interconversion of ADP into ATP and vice versa is, in fact, constant in a cell. Very little quantities of ATP are ever stored and a typical mammalian cell turns over – i.e. completely breaks down and replaces – its entire ATP pool every 1-2 minutes. In other words, an adult converts a quantity of ATP corresponding to about half his or her body weight every day, and nearly a ton during a day of hard work.

Energy for ATP synthesis

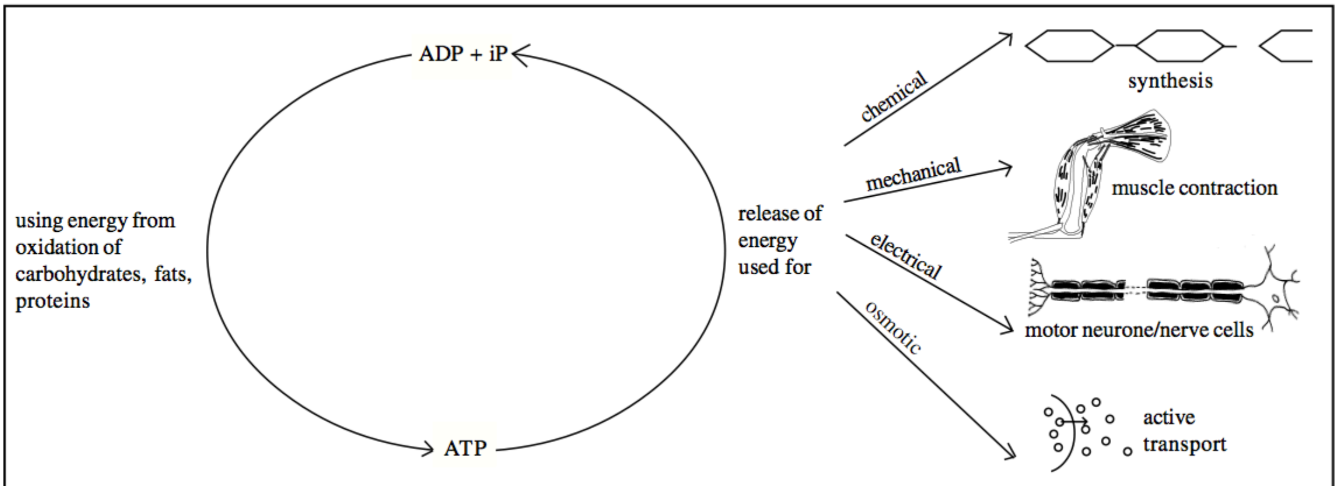
In all living things there are just two ways of supplying the energy for ATP production.

1. Substrate level phosphorylation. At AS/A2 level you do not need to know this term. Suffice to say that this is the process that makes ATP in glycolysis and in the Krebs cycle, for example.

2. Chemiosmosis . Again, you do not need to know this term but it is described in detail in all of the common A level textbooks and it is useful to know a little because it helps to make sense of what happens to the electrons in the electron transfer chain (ETC) in the cristae of the mitochondria (Fig 4).

> ***Remember***
> *Respiration = glycolysis + Krebs cycle + ETC*
> *(cell cytoplasm) (matrix of mitochondria) (cristae of mitochondria)*
> *See Factsheet 12 Respiration for more detail*

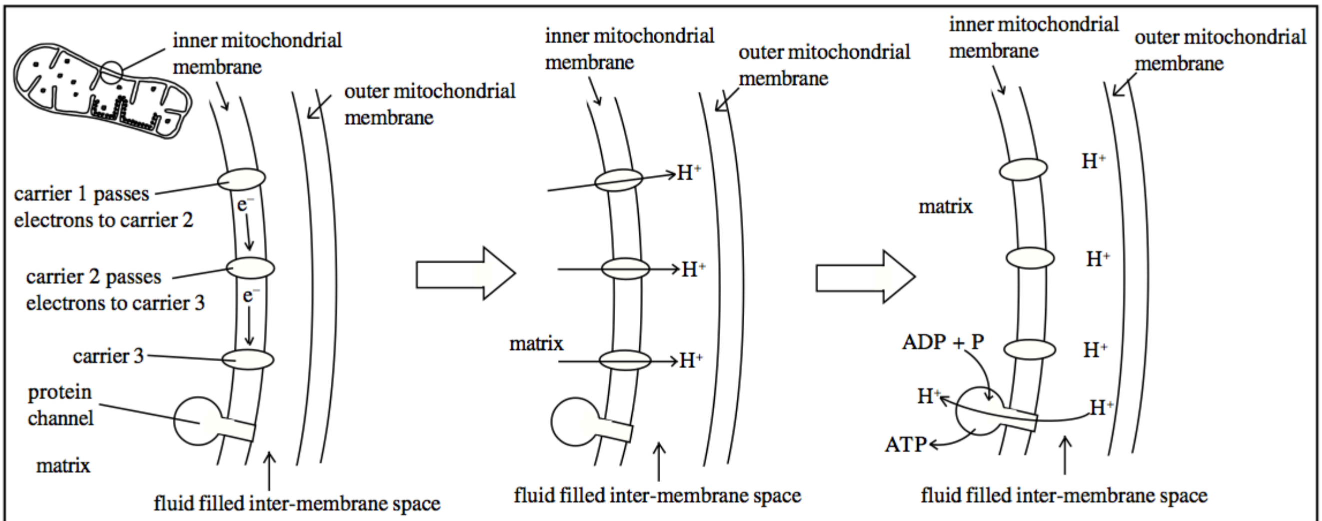
Fig 3. Uses of ATP



Chemiosmosis and the ETC

The main points are summarised in Fig 4.

Fig 4. Releasing electrons to make ATP



1. Electrons are passed from one electron carrier to another. Carriers include molecules such as NAD and FAD. The carriers are at progressively lower energy levels. As an electron passes from a carrier which is at a high energy level to a carrier that is at a lower energy level, energy is released.

2. This energy is used to pump H^+ ions into the space between the two membranes of the mitochondrial envelope. The concentration of H^+ ions inside the inter-membrane space then exceeds the concentration in the matrix; a concentration gradient has been established.

3. H^+ ions then move back into the matrix through protein channels in the inner membrane. These channels also contain the enzyme ATPase (ATP synthase or synthetase in some books). The electrical potential energy of the H^+ ions is used by the enzyme ATPase to make ATP from ADP and inorganic phosphate.

What is ATP used for?

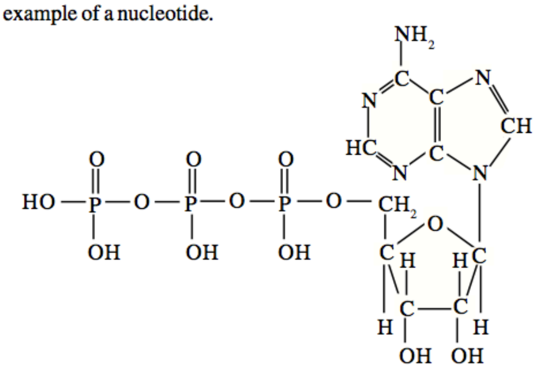
Table 1 summarises some of the important uses of ATP that appear on A level specifications

Table 1 uses of ATP

Use	Example
Active transport	Pumping Na^+ ions out of cells
Condensation reactions	Joining two peptides into a dipeptide
Glycolysis	Glucose + ATP........glucose-6-phosphate
Protein synthesis	Attaching a specific amino acid to its t-RNA molecule
Cell division	Chromosome movement towards the spindle pole
Muscle contraction	ATP energy needed to swivel the myosin head
Movement	Flagella of sperm, cilia
Bioluminescence	In fire-flies
Photosynthesis	Provides energy for Light Independent stage when CO_2 is reduced

Practice Questions

1. The diagram shows the structure of ATP. Explain why ATP is an example of a nucleotide. **2**



2. The table shows the energy content of some metabolites.

Metabolites	Energy content (k cal mol^{-1})
phosphoenolpyruvate	-14.8
1,3-Biphosphoglycerate	-11.8
Ceratine phosphate	-10.3
Adenosine triphosphate	-7.3
Adenosine diphosphate	-6.6
Glucose-1-phosphate	-5.0
Fructose-6-phosphate	-3.8
Adenosine monophosphate	-3.4
Glucose-6-phosphate	-3.3
Glycerol-3-phosphate	-2.2

Suggest why these data help explain the universal role of ATP as an energy conversion molecule. **3**

Answers

1. Nucleotides consist of a nitrogen-containing base, a pentose sugar and one or more phosphate groups;
In ATP the base is adenine, the sugar ribose and there are 3 phosphate groups;

2. ATP occupies intermediate energy level;
Molecules above it in the table will lose a phosphate group and the energy released will be used to convert ADP into ATP;
Molecules below it will stimulate hydrolysis of ATP, releasing energy for other chemical reactions/energy – requiring processes etc;

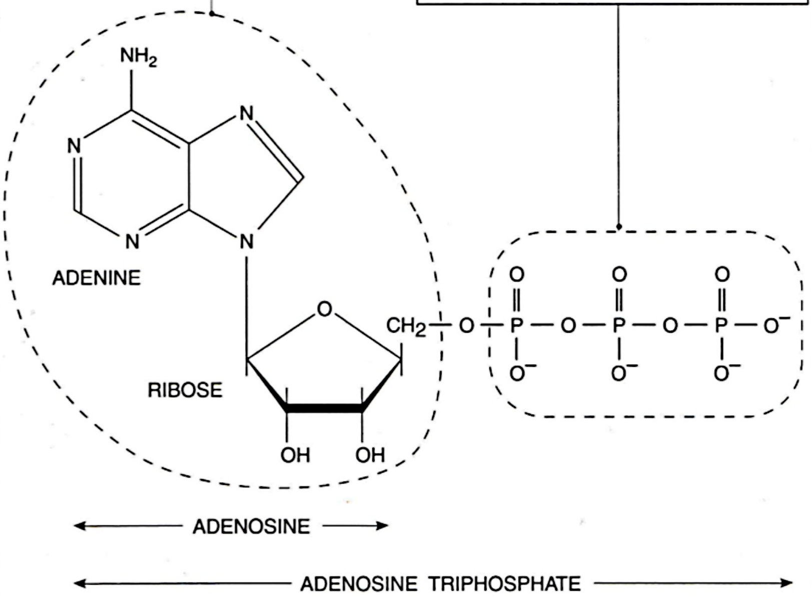
Acknowledgements:
This Factsheet was researched and written by Kevin Byrne.
Curriculum Press, Bank House, 105 King Street, Wellington, Shropshire, TF1 1NU

Section L Energy and ecosystems

ATP: the energy currency of the cell

This part of the molecule acts like a 'handle' – it has a shape which can be recognised by highly specific enzymes.

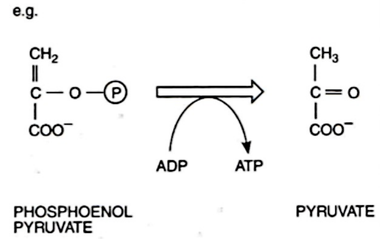
This part of the molecule contains anhydride bonds (O-P) which can be hydrolysed in reactions which are **exergonic** (energy-yielding) and can be coupled to **endergonic** (energy-demanding) reactions.

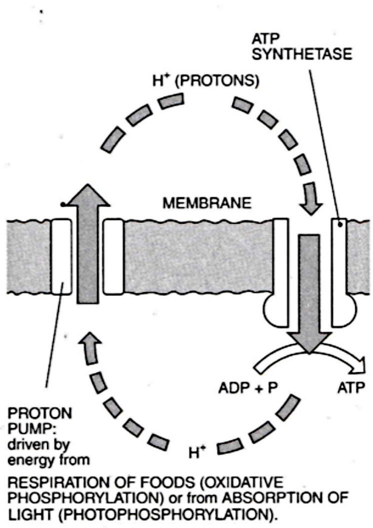


- ATP is **A**denosine **T**ri **P**hosphate.
- It is produced by adding phosphate (P) to ADP.
- When it is hydrolysed, energy is released to drive biological processes.

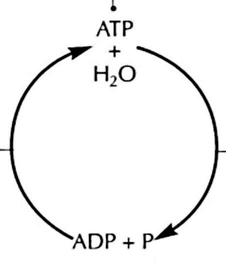
Substrate level phosphorylation: A phosphate group is transferred from a phosphorylated compound to ADP.

e.g.





Chemiosmosis: A proton gradient across an impermeable membrane is dissipated and the energy released is used to drive the phosphorylation of ADP.



Muscle contraction: ATP hydrolysis changes the position of the myosin 'head' relative to actin.

Urea synthesis: ATP hydrolysis drives the ornithine cycle which removes toxic ammonia.

$2NH_3 + CO_2 + 3ATP + 3H_2O \rightarrow urea + AMP + 2ATP$

Protein synthesis: ATP is used to 'load' amino acids onto transfer RNA.

Active transport systems are driven by the phosphorylation of membrane-bound proteins.

Calvin cycle (dark stage of photosynthesis): ATP hydrolysis drives the cyclic reduction of CO_2 to triose phosphate.

$3CO_2 + 6ATP \rightarrow$ triose phosphate

Nitrogen fixation involves the ATP-driven reduction of molecular nitrogen.

$N_2 + 8[H] + 12ATP \rightarrow 2NH_4^+ + 12\ ADP + 12P$

Bioluminescence: ATP hydrolysis drives the oxidation of luciferin which releases some energy as visible light – useful for fireflies!